MATH AND SCIENCE @ WORK

AP* CHEMISTRY Student Edition

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GENERATING WATER IN SPACE

Background

The International Space Station (ISS) is a research laboratory assembled in low-Earth orbit. Construction of the ISS began in 1998, and it was completed in 2011. Crews aboard the ISS conduct experiments in biology, chemistry, physics, medicine, and physiology, and make observations in astronomy and meteorology. The microgravity environment of space makes the ISS a unique laboratory for the testing of spacecraft systems that will be required for future exploration missions beyond low-Earth orbit.

The ISS is operated jointly among five participating space agencies: the United States' National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), the Russian Federal Space Agency (RKA), the Japan Aerospace Exploration Agency (JAXA), and the Canadian Space Agency (CSA).

Figure 1: The ISS orbiting the Earth as observed by Space Shuttle Discovery on March 7, 2011

An international crew, typically consisting of six members, resides on the ISS for approximately six months at a time. Since the first crew aboard the ISS in 1998, humans have maintained a permanent presence in space. In addition to the crews, personnel on the ground (located in Mission Control Centers) control the operations of the ISS.

Maintaining a permanent human presence on the ISS requires a well-organized and precise life support system. Flight controllers, known as Environmental and Thermal Operating Systems (ETHOS) operators, work in NASA's ISS Mission Control Center, and are responsible for the maintenance of this life support system. These operators also oversee the assembly and operation of multiple ISS subsystems and functions, including atmosphere control, supply and revitalization, internal thermal control, passive thermal control, temperature and humidity, fire detection and suppression, water recovery and management, and regenerative and emergency response. As ETHOS operators perform these duties, they are providing a safe environment for the ISS crew to live and perform valuable research in space.

Problem

The Sabatier Reactor is part of the Environmental Control and Life Support System (ECLSS) on the ISS. The Sabatier Reactor uses hydrogen gas and carbon dioxide to generate water and methane at a temperature of 673 K.

The hydrogen gas is obtained through water electrolysis, a function performed by another part of ECLSS (called the Oxygen Generating System). The carbon dioxide is captured from the ISS atmosphere. As a result, the water generated by the Sabatier Reactor can be purified and used as drinking water (with minerals added for taste), or can be used for other functions on the ISS. The methane is then vented into space.

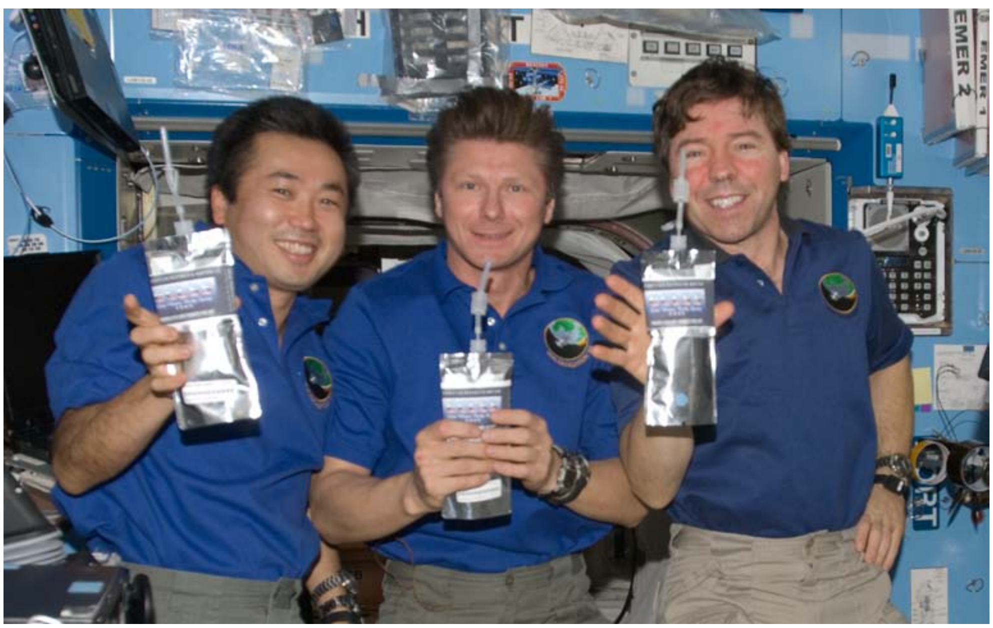

Figure 2: Expedition19 crewmembers are the first to drink recycled water produced on the ISS.

A. Using the provided information about the Sabatier Reactor and its use of hydrogen and carbon dioxide, answer the following questions in regard to the reaction.

   I. Write a complete balanced equation for the equilibrium reaction between hydrogen gas and carbon dioxide.

II. Write the equilibrium expression, K_c, for the reaction.

B. The Sabatier Reactor is projected to produce 909 kg of water per year. Calculate the number of grams of hydrogen gas that needs to be collected each month to produce this amount of water.

C. Calculate the change in enthalpy, ΔH°_{rxn}, for the reaction using the following bond energies.

Bond	**Bond Energies (kJ per mol)**
H-H	432
C=O	745
H-O	467
C-H	413

D. Calculate the change in entropy, ΔS°_{rxn}, for the reaction using the following table.

Substance	**ΔS° ($J\ K^{-1}\ mol^{-1}$)**
H_2	130.6
CO_2	213.6
H_2O	69.9
CH_4	186.2

E. Calculate the standard Gibbs free energy, $\Delta G°_{rxn}$, and the Gibbs free energy, ΔG_{rxn}, at 673 K.

F. Calculate the reaction quotient, Q, for the reaction.

G. Based on Le Chatelier's principles and the needs of the ISS, answer the following questions.

I. Why is it critical for this process on the ISS not to reach equilibrium?

II. Should the reaction quotient, Q, be less than or greater than the equilibrium constant, K? Explain your reasoning as it relates to the ISS.

III. With limited volume for this reaction, how would you keep the reaction flowing in the direction of the products?